quiescence and terrestrial magnetism. When the movement of the north "magnetic pole" is considered it appears that at these two very epochs it was passing through two critical points of its path—the first when it was at its nearest approach to the geographical pole, the second when it was at its greatest elongation from it.

The Aurora and Magnetic Disturbance.

By William Ellis, F.R.S.

In a paper that appeared in the *Monthly Notices* of the Society for 1899 December, on the relation between magnetic disturbance and the period of solar-spot frequency, I showed from the observations of the fifty years 1848 to 1897 at the Royal Observatory, Greenwich, the general relation existing between the period of solar-spot frequency and the frequency of magnetic disturbance in the progression from Sun-spot maximum to Sun-spot minimum, and again from Sun-spot minimum to Sun-spot maximum; and further pointed out that, in addition, there existed in the frequency of magnetic disturbance an annual inequality that has no counterpart in the march of Sun-spot frequency. In a following paper appearing in the *Monthly Notices* for 1901 June, I compared this seasonal variation in the frequency of magnetic disturbance at Greenwich with the variation in frequency of the *Aurora* in the same locality, showing that in both phenomena there existed maximum epochs at or near the equinoxes, and minimum epochs at or near the solstices. I now desire to pursue the question a little further.

As regards the *Aurora*, although in our latitude there is, as mentioned, maximum of frequency at the equinoxes and minimum of frequency at the solstices, this condition undergoes modification in higher latitudes, the winter minimum becoming less pronounced as higher latitudes are approached, until it altogether disappears. In the recently published *Catalog der in Norwegen bis Juni 1878 beobachteten Nordlichter*, J. Fr. Schroeter has combined the work of Tromholt for Norway and Rubenson for Sweden, and formed abstracts that give, separately for each one of five latitudinal regions over Scandinavia, the monthly frequency of the *Aurora* as found from observations, many thousands in number, made during the years 1761 to 1877. And from a paper by Mr. R. C. Mossman "On the Aurora Borealis in London," contained in the *Journal of the Scottish Meteorological Society*, third series, vol. xi. p. 58, corresponding information is to be found for other positions south of the above. To these I have added the monthly frequency of magnetic disturbance at Greenwich and Paris. The various numerical results are given in the annexed table, in each case in percentage of the total frequency.

Month.	Frequency of the Aurora. Scandinavia, 1761–1877. North of 68½°.	68½° to 65°.	65° to 61½°.	61½° to 58°.	South of 58°.	North East of Scotland, 122 years. 57½°.	Edinburgh, 81 yrs. 56°.	London, 189 years. 51½°.	Frequency of Magnetic Disturbance. Royal Observatory, Greenwich, 50 years. 51½°.	Parc St.-Maur, Paris, 5 years. 49°.
July	0·0	0·0	0·0	0·4	0·6	0·4	1·8	1·9	7·0	7·9
Aug.	0·4	1·1	2·8	5·7	4·9	4·4	6·4	5·6	7·5	10·7
Sept.	7·8	9·7	13·1	13·6	14·9	12·9	12·3	14·5	9·9	12·1
Oct.	15·1	14·6	14·2	13·8	13·5	15·8	13·9	16·9	10·4	9·3
Nov.	14·4	14·0	12·8	10·4	10·3	12·0	11·7	9·6	8·4	8·7
Dec.	15·7	14·1	11·5	9·6	8·2	9·6	4·8	6·4	7·1	5·6
Jan.	16·4	15·3	13·2	9·5	8·2	10·9	10·0	8·6	8·0	5·9
Feb.	13·8	14·6	12·3	11·2	11·9	12·7	12·3	10·5	9·9	6·7
Mar.	14·8	13·7	14·5	13·5	12·6	12·0	13·9	10·2	10·3	10·2
Apr.	1·6	2·9	5·4	10·9	13·3	7·1	9·0	10·7	8·9	7·7
May	0·0	0·0	0·2	1·3	1·5	2·2	3·6	4·0	7·1	8·2
June	0·0	0·0	0·0	0·1	0·1	0·0	0·3	1·1	5·5	7·0

(Latitude North.)

The numbers for the five Scandinavian regions are taken from page 420 of the before-mentioned *Catalog*, and those for the North-east of Scotland, Edinburgh, and London from the paper by Mr. Mossman. These are all percentage values. As regards magnetic disturbance at Greenwich, the days of moderate, active, and great disturbance, appearing in Table I. of my paper (*Monthly Notices*, 1899 December), have been combined and re-arranged for each month respectively on the aggregate of the fifty years employed. The days thus included are those on which disturbance occurred in declination greater than 10′, or in horizontal force greater than ·00050 c.g.s. The resulting values (monthly number of days) commencing with July are 282, 301, 401, 420, 339, 285, 322, 400, 416, 359, 289, and 223, which were converted into percentage values for insertion in the table. For Paris, M. Moureaux, in a paper *Sur la périodicité des perturbations de l'aiguille aimantée horizontale à l'Observatoire du Parc Saint-Maur*, has given, for the five years 1883 to 1887 * the number of disturbances exceeding in declination 3′ and in horizontal force ·00020 c.g.s. for each month on the aggregate of the whole five years. But as the variation in the monthly values is very similar in both elements, I have for the present purpose combined them in one series, giving for the several months commencing with July the numbers 622, 846, 955, 729, 687, 444, 468, 527, 801, 607, 643, and 554 respectively, which, similarly

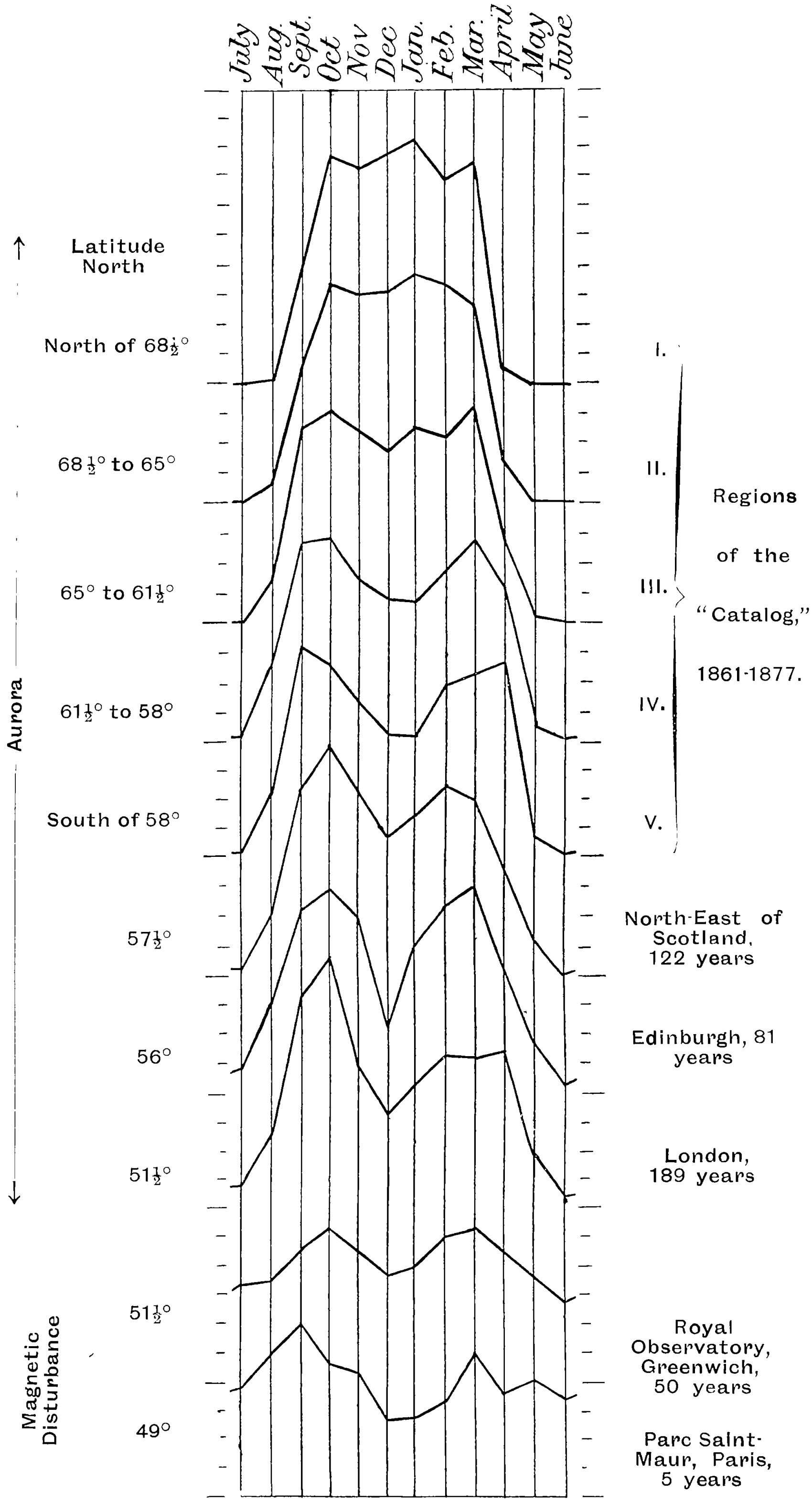
* *Annales du Bureau Central Météorologique de France*, Année 1887. *Mémoires*, p. B. 35. (In a later volume for 1897 M. Moureaux has given similar information for the fifteen years 1883 to 1897.)

converted into percentage values, are the numbers appearing in the table, the contents of which are graphically represented in fig. 1 (Plate 14).

It will be remarked that the curves of frequency of magnetic disturbance at Greenwich and Paris are very similar, showing maxima at or near the equinoxes and minima at or near the solstices, and similar also to that of the aurora at London, excepting that the autumn maximum of the latter is of more pronounced character than that of spring, as is also the case in the north-east of Scotland. It will be further observed that the strongly marked winter minimum of the aurora in lower latitudes becomes less and less marked as more northern latitudes are approached; in regions IV. and III. it is distinctly less marked, and in regions II. and I. it disappears. The autumn maximum visibly tends to become later, and the spring maximum somewhat earlier as the higher latitudes are approached, the winter depression at the same time diminishing until eventually there remains only a mid-winter maximum at or near the winter solstice. The mid-winter minimum of lower latitudes being thus converted in higher latitudes into a mid-winter maximum, it becomes a question, remarking the similarity of the auroral and magnetic curves in lower latitudes, as to what happens in higher latitudes as regards magnetic disturbance. Does it still run with the aurora? That is, does the winter depression of frequency in higher latitudes become similarly converted into a mid-winter maximum. By analogy this might be expected to be the case. But is it so? The summer effect is not easily discussed as regards aurora, because of the daylight towards the north; the winter effect is, however, readily followed, and the condition of things is clear, but information appears to be wanting as regards what happens in the case of magnetic disturbance.

It may be well to give some further indication of the really persistent character of the seasonal variation in frequency of magnetic disturbance in our latitude. The agreement between the curves for Greenwich and Paris shown in fig. 1 is sufficient evidence of the existence of the inequality, but the question may be somewhat further illustrated. For this purpose the number of days of magnetic disturbance at Greenwich during four years about each of the Sun-spot maxima of 1848, 1860, 1870, 1884, and 1894 were grouped together as indicating periods of greater frequency of disturbance, and similarly for four years about each of the Sun-spot minima of 1856, 1867, 1879, and 1890, as indicating periods of lesser frequency of disturbance, the two groups so formed containing twenty and sixteen years respectively, as follows, the comparision showing here, in addition to the law of frequency, also the absolute number of days involved.

Fig. 1.—Annual Inequality of Aurora and of Magnetic Disturbance.



Each division of the scale represents 2·0 of the percentage values of the Table. The longer lines of the scale indicate the zeros of the several curves.

Number of days in the twenty years of greater frequency of magnetic disturbance (near Sun-spot maximum).

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1848–1851	22	13	32	36	25	24	25	35	22	21	22	13
1858–1861	24	33	38	44	14	29	22	25	44	33	20	24
1869–1872	32	41	45	39	31	26	30	39	50	54	34	27
1882–1885	28	27	29	29	35	20	20	32	30	34	23	24
1892–1895	41	22	48	49	36	32	35	53	56	30	32	36
Total for 20 years ...	147	136	192	197	141	131	132	184	202	172	131	124
Monthly Mean ...	7·4	6·8	9·6	9·9	7·0	6·5	6·6	9·2	10·1	8·6	6·5	6·2

Yearly average = 94·4 days.

Number of days in the sixteen years of lesser frequency of magnetic disturbance (mean Sun-spot minimum).

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1854–1857	9	13	21	18	16	11	17	30	25	24	14	6
1865–1868	20	26	43	50	30	6	25	41	30	24	18	12
1876–1879	4	3	7	4	12	8	7	4	7	5	9	3
1887–1890	20	27	25	29	35	17	23	37	22	22	22	10
Total for 16 years ...	53	69	96	101	93	42	72	112	84	75	63	31
Monthly Mean ...	3·3	4·3	6·0	6·3	5·8	2·6	4·5	7·0	5·3	4·7	3·9	1·9

Yearly average = 55·6 days.

The monthly means of the two groups are graphically represented in fig. 2. We see for the years about maximum of Sun-spots that, on the average, magnetic disturbance occurred on some ninety-four days of the year, and about minimum of Sun-spots on some fifty-five days. But the point to which attention is to be drawn (see fig. 2) is the circumstance that the annual inequality is shown not only in periods of greater frequency of magnetic disturbance near to Sun-spot maximum, but that it is also strongly marked in periods of lesser frequency near Sun-spot minimum. It will be seen also that with some few irregularities the inequality can be very well followed in the separate four yearly groups of years about Sun-spot maximum and Sun-spot minimum. It may be added that in the fourteen years of the fifty years employed that remain intermediate between the epochs of maximum and minimum and of minimum and maximum of Sun-spots, the winter minimum is much less pronounced, the summer minimum remaining much the same, on the whole producing a flatter curve, as indicated by the thin line in fig. 2, for which (without giving all the corresponding figures) it may be added that the monthly means (number of days) commencing with July are 5·9, 6·9, 8·1, 8·7, 7·5, 8·0, 8·4, 7·4, 9·3, 8·0, 6·8, and 4·9. The annual inequality is thus most strongly developed near epochs of maximum and minimum of Sun-spots.

It may be that the flatter intermediate curve is in some measure due to accidental circumstances.

The magnetic disturbance that has been here dealt with is, as before mentioned, that taken as including days of moderate, active, and great disturbance at Greenwich, according to the convention of the previously mentioned paper of 1899 December. But it may be further pointed out that considering separately the frequency of these three different degrees of disturbance, it is found that the excess of the equinoctial frequency over the solstitial frequency is greater, the greater the degree of disturbance. The three degrees are thus defined :—(1) moderate, indicating disturbance in declination greater than 10′ but less than 30′, and in

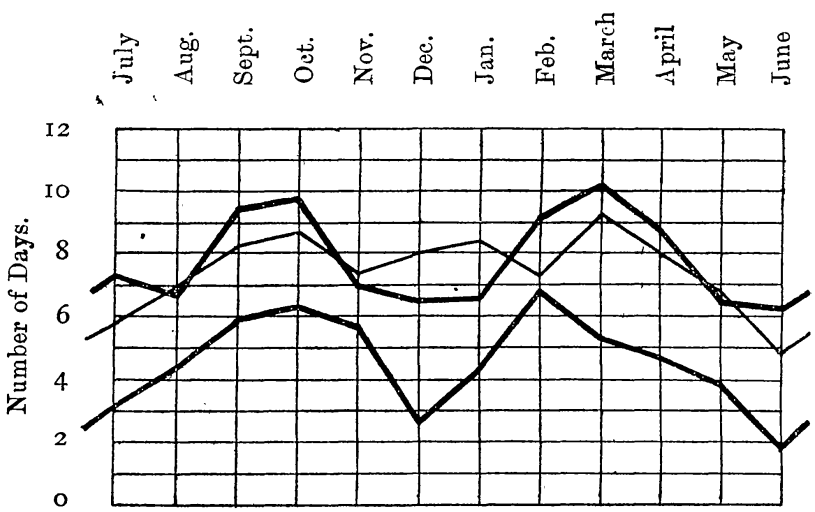


FIG. 2.—Annual Inequality of Magnetic Disturbance at Greenwich.

The upper thick line indicates the annual inequality in frequency of disturbance near maximum of Sun-spots, and the lower thick line that near minimum of Sun-spots ; the thin line represents the inequality in years intermediate between these extreme epochs.

horizontal force greater than ·00050 but less than ·00150 c.g.s. ; (2) active, indicating disturbance in declination greater than 30′ but less than 60′, and in horizontal force greater than ·00150 but less than ·00300 c.g.s. ; and (3) great, indicating disturbance in declination greater than 60′, and in horizontal force greater than ·00300 c.g.s., the three months of February to April, and from August to October, being taken as equinoctial, and the remaining six months as solstitial.

Degree of Disturbance.	Number of Days.	Frequency of Disturbance (Percentage). Equinoctial.	Solstitial.	Excess of Former.
Moderate	3,663	56	44	12
Active	299	61	39	22
Great	75	71	29	42

In this table no regard is paid to Sun-spot frequency, the whole fifty years being alike employed. It thus finally appears :

(1) That the annual inequality in frequency of magnetic disturbance at Greenwich is strongly marked, not only at periods of greater frequency and correspondingly greater magnitude of disturbance near Sun-spot maximum, but also at periods of lesser frequency and correspondingly lesser magnitude of disturbance near Sun-spot minimum.

(2) Also that the annual inequality in frequency of disturbance is greater as the degree of disturbance becomes increased.

These conclusions may appear to be in some sense contradictory. But it is to be remarked (fig. 2) that although the lower thick line includes a less number of days—that is, on the whole, a lesser numerical frequency of disturbance—than does the upper thick line, the inequality in frequency is of similar character in both. For although the frequency of active and great disturbance influences mainly the upper thick line, it also affects in no inconsiderable degree some of the years that become included in the formation of the lower thick line.

Now, if disturbance frequency progresses as does the 11± year Sun-spot frequency—that is, on the whole, with no annual period,* the mean monthly number of days of disturbance taken through a series of years should similarly, as the number of years employed is increased, more and more approximate to equality of value in all months of the year, by gradual elimination of the transient fluctuations of value, instead of which the combination of years really brings out a definite annual inequality in frequency to be observed, as already mentioned, in the four yearly groups of years, but distinctly shown in the aggregate, alike in the years of maximum frequency and minimum frequency of disturbance, diminished in the latter case as to the absolute number of days of disturbance in the various months of the year, but still showing a most marked annual inequality, which can only be understood as an undoubted physical effect.

The annual inequality in the frequency of magnetic disturbance in our latitude has thus a real existence. Our knowledge of the relations subsisting between solar and other phenomena, so far as our own geographical position is concerned, has also reached a certain definite stage—that is to say, as regards the 11± year Sun-spot cycle, a period of great solar activity is also one of great magnetic activity with frequent displays of the aurora,† and a period of solar quiet is similarly also one of magnetic quiet, with no exhibitions of the aurora. It is thus apparent :—

(1) That in addition to the progression in frequency of magnetic disturbance and of the aurora in harmony with the 11± year Sun-spot period, there exists in both phenomena, in

* *Monthly Notices*, 1899 December, p. 152.

† At Greenwich magnetic disturbance is not necessarily accompanied by aurora, but when aurora does appear there is also magnetic disturbance.

our latitude, an annual inequality having maxima at or near the equinoxes and minima at or near the solstices to which there is no counterpart in the progression of solar-spot frequency.*

(2) That the equinoctial maxima of frequency in the case of the aurora disappear in higher latitudes, becoming merged into a single midwinter maximum, with entire disappearance of the winter minimum.

Thus, viewing the relation that exists in our latitude between the annual inequality of magnetic disturbance and of the aurora, and the modification that the inequality undergoes in higher latitudes in the case of the aurora, it becomes of interest to ask whether in the case of magnetic disturbance any similar modification of the inequality occurs? As already remarked, I do not know of any available information bearing thereon.

To turn now from the question of the annual inequality in frequency of the aurora to another matter, the relation of the aurora to the 11 ± year Sun-spot period, it appears from observations made at Ivigtut, in Greenland,† in latitude 61° north, at Godthaab in 64° north, and at Jacobshavn in 69° north, that years of greater frequency of the aurora were years of lesser frequency of Sun-spots. But Rubenson ‡ having discussed the Swedish observations made between the years 1721 and 1877, has represented them by formulæ, n being the number of years after the initial epoch, as follows :—

$$1728{\cdot}2 + 11{\cdot}07 \times n, \text{ for maximum,}$$

$$1734{\cdot}2 + 11{\cdot}03 \times n, \text{ for minimum,}$$

and found that the observed epochs of maximum and minimum frequency of the aurora during the period mentioned were, with a few exceptions, in close agreement with corresponding epochs calculated from the formulæ, indicating also a near agreement with the corresponding maximum and minimum epochs of Sun-spots. Rubenson suspects that there may be long period variations in the aurora, but as to the existence of such variations in these and related phenomena there appears at present, I think, to be a good deal of uncertainty. But as to the 11 ± year period his results appear to be opposed to those found at stations in Greenland as above given, which indicate greater frequency of aurora with lesser frequency of Sun-spots, although situated in the same latitudinal zone. It may be of interest to examine a little more closely this point. In Rubenson's work (p. 298) a table is given showing the epochs of maximum and minimum frequency of the aurora as determined from the Swedish observa-

* The annual inequality in the diurnal range of the magnetic elements is similarly a terrestrial effect that has no counterpart in the progression of Sun-spot frequency.

† *Exploration Internationale des Régions Arctiques*, 1882–3, *Expédition Danoise*, tome i. p. 19.

‡ *Catalogue des Aurores Boréales observées en Suède depuis le xvi^me siècle jusqu'à l'année* 1877.

tions, those epochs which are supposed to be more or less doubtful being placed in parentheses. Omitting these latter, and comparing the remaining values with the corresponding Sun-spot epochs taken from Professor Wolfer's paper in the *Meteorologische Zeitschrift* for 1902 May, we have the annexed table.

Observed Epochs of Maximum and Minimum Frequency of the Aurora and of Sun-spots Compared.

Maximum Epochs			Minimum Epochs.		
Rubenson. (Aurora.)	Wolfer. (Sun-spot.)	Excess of Former.	Rubenson. (Aurora.)	Wolfer. (Sun-spot.)	Excess of Former.
1729·9	1727·5	+2·4	1736·6	1734·0	+2·6
1741·2	1738·7	+2·5	1744·3	1745·0	−0·7
1749·9	1750·3	−0·4	1756·0	1755·2	+0·8
1761·0	1761·5	−0·5	1777·8	1775·5	+2·3
1788·3	1788·1	+0·2	1798·6	1798·3	+0·3
1804·6	1805·2	−0·6	1811·8	1810·6	+1·2
1819·6	1816·4	+3·2	1824·4	1823·3	+1·1
1831·7	1829·9	+1·8	1834·2	1833·9	+0·3
1839·0	1837·2	+1·8	1844·7	1843·5	+1·2
1851·0	1848·1	+2·9	1856·3	1856·0	+0·3
1871·3	1870·6	+0·7			
Mean	... ...	+1·3	Mean	... ...	+0·9

The epochs of maximum and minimum frequency of the aurora thus appear to fall respectively at or near to maximum and minimum epochs of Sun-spots as in our latitude, but following the Sun-spot epochs a little later in time, and on the whole by a longer interval at maximum epoch than at minimum epoch. There are irregularities, however, in the progression of auroral frequency as well as in that of Sun-spot frequency. Thus the 1788·3 observed maximum epoch of aurora was a greatly accelerated one, arriving 6·3 years earlier than the calculated time by the formula for maximum above given, which is 1794·6. And Professor Wolfer, who gives the observed Sun-spot maximum as 1788·1, has also added formulæ to represent the observed values, as follows:

$$1749{\cdot}37 + 11{\cdot}091 \times n, \text{ for maximum,}$$

$$1744{\cdot}21 + 11{\cdot}141 \times n, \text{ for minimum,}$$

from which the calculated time of maximum is found to be 1793·7, the observed time being thus 5·6 years earlier. That acceleration of the auroral maximum by 6·3 years should be accompanied by an acceleration of the Sun-spot maximum by 5·6 years is a striking proof of the interrelation of the two phenomena, since they thus remain in close accord, the auroral maximum exceeding the Sun-spot maximum (see the preceding table)

by only 0·2 year. We may also compare the formulæ of Rubenson for aurora with those of Wolfer for Sun-spots by reducing them to two epochs, one near the beginning and one near the end of the series for aurora employed, as follows :—

Maximum Epochs.			Minimum Epochs.		
of Aurora. (Rubenson.)	of Sun-spots. (Wolfer.)	Excess of Former.	of Aurora. (Rubenson.)	of Sun-spots. (Wolfer.)	Excess of Former.
1750·3	1749·4	+0·9	1745·2	1744·2	+1·0
1872·1	1871·4	+0·7	1866·6	1866·8	−0·2

giving mean differences of +0·8 year and +0·4 year respectively as compared with +1·3 year and +0·9 year, found by comparison of the epochs as observed, in which latter (as before mentioned) a few epochs of aurora understood to be somewhat doubtful were not included. These results indicate that throughout Sweden, during the period covered by the observations discussed, the times of maximum and minimum frequency of the aurora were, on the whole, in close relation with those of maximum and minimum frequency of Sun-spots, both phenomena being, with the 11± year periodical variation of magnetic diurnal range and of magnetic disturbance, all alike the effect of some common unknown cause.

What is already known as regards the relations existing between solar-spots, terrestrial magnetism, and the aurora in middle latitudes may be but an outer fringe of the subject, but corresponding information in regard to polar regions is not to the same extent available. As regards magnetism, observations in those regions have hitherto been more or less of a temporary nature. But to obtain any sufficient knowledge of the physical constitution of the globe, observatories, not of temporary but of permanent character, are necessary in all regions, as well as in the more habitable portions of the globe, and the north polar regions offer opportunities for placing such observatories as do not exist in the same way in the south.

Our Earth is more and more found to be not an isolated body simply receiving light and heat from the Sun, as formerly commonly conceived, but one subject to other external influence made manifest to us in various ways with which we have only in later times for the most part become acquainted, but of the precise nature of which little more is known than that, complex in action, it seems to be one that may pervade the whole solar system, involving in one common field of action all the bodies thereof. If we could plant observatories on some of the other planets of our system, and communicate therewith, how enlarged might be our knowledge of the action of the forces that surround us.